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MONOMETAMORPHISM, POLYMETAMORPHISM, AND RETROGRADE METAMORPHISM

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ABSTRACT. Retrograde metamorphism, defined as a mineralogical readjustment of high temperature metamorphic assemblages to a lower temperature, is not necessarily a change in response to falling temperature. The term "polymetamorphic diaphthoresis" is introduced to designate retrograde changes, perhaps in response to rising temperature, during a second period of metamorphism, which is distinctly separated from an earlier higher grade metamorphism.

Turner (1948, p. 6) defined polymetamorphism as a "reconstitution of rocks in more than one stage, each governed by distinct physical or chemical conditions; for example, dynamometamorphism during orogenic deformation, followed by contact metamorphism under static conditions following late injection of granitic intrusions."

Read (1949, p. 130) attempted a more restricted definition of polymetamorphism. He pointed out that:

> "We can separate two ideal cases. In the first, the series of episodes of crystallization and deformation, though alternating and not strictly coeval, can reasonably be considered parts of a unified whole; though we may here be busy with the details of a lengthy and complex sequence of deformation, rotation of porphyroblasts, replacement, crystallization and other operations, we are satisfied that all these operations belong to one self-contained act in the history of the rock—the rock is monometamorphic. Second, there is the case of two or more unified acts that are separable from one another and present no obvious genetic connection—the rock recording such a history is polymetamorphic."

Dorothy Wyckoff (1952) studied the Wissahickon schist near Philadelphia and reported a case of "reconstitution of rocks in more than one stage" of metamorphism. Reportedly, an earlier episode of high temperature metamorphism was followed by an episode of more intense hydrothermal metamorphism in response to *falling* temperature. As all these metamorphic changes, in her opinion, apparently, took place during one general period of deformation and plutonism, they should perhaps be considered monometamorphic rather than polymetamorphic.

Rocks in certain regions have undergone two or more periods of deformation and metamorphism that were distinctly separated. Sutton and Watson (1951) discovered a period of volcanism separating two periods of metamorphism in the northwestern Scottish Highlands; they postulated accordingly two periods of orogenic movement in the Highlands during Precambrian time. Brothers (1954) recently found partially altered tectonic inclusions of eclogite and amphibolite in serpentine intrusives of the Franciscan group at Berkeley Hills, California. The results of his work not only suggest a polymetamorphic history for the Coast Range of California but also give us some clues as to the kind of basement upon which the Franciscan sediments were laid down. The writer (Hsu, 1955) found that the rocks of the Cucamonga Canyon area, Southeastern San Gabriel Mountains, California, have also been repeatedly deformed and metamorphosed. North-trending granulites, perhaps metamorphosed during Precambrian time, were changed to east-trending amphibolite facies rocks during Mesozoic (?) metamorphism. A period of sedimentation (Paleozoic ?) intervened between the two periods of mountain-making; the Paleozoic (?) sediments were not affected by the

Precambrian (?) deformation, but were metamorphosed during the Mesozoic (?) orogeny. Furthermore, the Mesozoic (?) amphibolite facies metamorphism was separated by Miocene (?) volcanism from a still later greenschist facies metamorphism, which was localized along Tertiary fault zones. The repeated metamorphic changes of the rocks in Cucamonga Canyon area were not retrogressive processes in response to *falling* temperatures during Precambrian (?) time; rather they represent three distinct periods of deformation and metamorphism (Precambrian ?, Mesozoic ?, Tertiary ?). Each period in turn considered of several minor episodes or phases (for example, the Mesozoic (?) metamorphism of the area was represented by an earlier phase of dynamothermal metamorphism and a later phase of thermal metamorphism).

The examples cited above should suffice to demonstrate the importance of distinguishing polymetamorphism from monometamorphism that consists of several episodes. As an indiscriminate use of the term "polymetamorphism" may create erroneous impressions, the writer suggests that we follow Read (1949) to define polymetamorphic rocks in a restricted sense. Only rocks which record a history of two or more periods of metamorphism that present no obvious genetic connection are polymetamorphic. Rocks that have been reconstituted repeatedly during different stages of one single period of metamorphism should be known as monometamorphic.

Retrogressive metamorphism (retrograde metamorphism, or diaphthoresis) has been considered a special type of polymetamorphism (Turner, 1948, p. 6). Harker (1939, p. 344) used the term retrograde metamorphism to denote metamorphic changes in response to *falling* temperatures, "thus emphasizing its essential nature as a reversal, or partial reversal, of metamorphism proper." Turner defined retrogressive metamorphism as a "mineralogical readjustment of high-temperature metamorphic assemblages to a lower temperature" (Turner and Verhoogen, 1951, p. 413). However, such a readjustment is not necessarily a metamorphic change in response to *falling* temperature. In all the examples of polymetamorphism previously discussed (Sutton and Watson, 1951, etc.), high temperature assemblages formed during a first period of metamorphism were converted to lower temperature assemblages during a second period of lower grade metamorphism, perhaps in response to *rising*, not *falling*, temperatures. Thus, Harker's and Turner's definitions of retrogressive metamorphism are in some instances in direct conflict.

The concept of diaphthoresis was first introduced by Becke (1909) to explain the occurrence of relic crystals of high temperature minerals in low grade schists. Becke did not present enough evidence to indicate if such changes are monometamorphic or polymetamorphic. Perhaps we should follow Turner (1948, p. 6) to designate diaphthoresis (retrogressive or retrograde metamorphism) to include all metamorphic processes through which "a metamorphic assemblage of minerals formed at high temperature is converted to an assemblage stable at lower temperatures." For diaphthoretic changes in response to *falling* temperatures during monometamorphism (as that described by Wyckoff, 1952), we might use the term *monometamorphic diaphthoresis.* For diaphthoretic changes in response to *rising* or *falling* temperatures during a later period of metamorphism, we might use the term *polymetamorphic diaphthoresis.*

E. B. Knopf (1931) discussed the problem of retrogressive metamorphism. She reasoned that mineralogical readjustments "are slowed down or inhibited by lowering of temperature," thus answering the question "Why are not all rocks as we now see them diaphthorites?" On the other hand, she was not quite certain "Why do diaphthorites ever form?" She speculated (p. 6-7):

> "The mere fact that katagneisses do arrive at the surface shows that the rock is able to remain in a condition of apparent (or false) equilibrium even after removal to a new environment to which it is unadjusted. But a katagneiss that has arrived at the Earth's surface as a result of denudation or by any simple upward movement *en bloc* has remained undisturbed by the movement as far as its constituent parts are concerned. All diaphthorites on the other hand are tectonites, and thus affected by the movement down to their ultimate constituents, so that retrogressive crystallization was induced by the differential movements that caused the deformation."

The writer does not know of any positively proven cases of intense monometamorphic diaphthoresis. On the other hand, polymetamorphic diaphthorites are not uncommon (Read, 1949; Sutton and Watson, 1951; Brothers, 1954; Hsu, 1955). Perhaps the concept that mineral reactions are deterred or inhibited by lowering of temperature is essentially correct, and most diaphthorites have been formed through polymetamorphism in response to *rising* temperature. The effect of deformation on diaphthoresis observed by Knopf is probably indirect. Structural control of localization of hydrothermal solutions may have resulted in local variations of the partial pressure of water in the system. Such variations in turn should result in the coexistence of "high grade" assemblages in equilibrium and "low grade" assemblages in equilibrium at the same temperature and confining pressure (Hsu, 1954). Thus, the preservation of apparently disequilibrium assemblages in polymetamorphic diaphthorites may be accounted for through a clear understanding of the role of water in metamorphism.

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